04-CHEM-A2, MECHANICAL and THERMAL OPERATIONS

December 2015

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an **open book exam.** One textbook of your choice with notations listed on the margins etc., but no loose notes are permitted into the exam.
3. Candidates may use any **non-communicating** scientific calculator.
4. All problems are worth 25 points. At least **two problems** from **each** of sections **A** and **B** must be attempted.
5. **Only the first two** questions as they appear in the answer book from each section will be marked.
6. State all assumptions clearly.

Section A: Mechanical Operations

A1. A mixture of two sizes of glass spheres of diameters 0.75 mm and 1.5 mm is fluidized by a liquid and complete segregation of the two species of particles occur, with the smaller particles constituting the upper portion of the bed and the larger particles in the lower portion of the bed. It may be assumed that the terminal falling velocities (u_c) of both particles may be calculated from Stokes' law, and that the relationship between fluidization velocity (u_0) and the bed voidage (e) is given by the equation

$$(u_c/u_0) = e^{4.6}$$

(a) **[20 points]** What will be voidage of the upper bed when the voidage of the lower bed is 0.6?

(b) **[5 points]** The bed velocity is increased until the smaller particles are completely transported from the bed. What is the minimum voidage of the lower bed at which this phenomenon will occur?

A2. In the filtration of a sludge, the initial period is effected at a constant rate with the feed pump at full capacity, until the pressure difference reaches 400 kN/m^2. The pressure is then maintained at this value for the remainder of the filtration. The constant rate operation requires 900 seconds and one-third of the total filtrate is obtained during this period. Neglecting the resistance of the filter medium and assuming the cake is not washed, determine the following if the time for removing the cake and reassembling the press is 1200 seconds:

(a) **[10 points]** The total cycle time.

(b) **[15 points]** The total cycle time with the existing pump for a maximum daily capacity.

A3. A 3-cm inside diameter pipe is being used to pump a liquid into a buffer tank. The tank is 1.5 m in diameter and 3 m high. The density of the liquid is 1040 kg/m^3 and viscosity is 1.6×10^{-3} Pa.s.

(a) **[12.5 points]** What is the minimum time to fill the tank with this liquid if it is flowing under laminar conditions in the pipe?

(b) **[12.5 points]** What is the maximum time to fill the tank with this liquid if it is flowing under turbulent conditions in the pipe?

Section B: Thermal Operations

B1. A long duct of square cross-section is at 15 °C, and the surrounding air is at 39 °C. All sides of the duct are surrounded by air, and each side of the duct is 32 cm. Using the thermo-physical properties of air at atmospheric pressure given below, find the rate of heat transfer per unit length.

T $[K]$	ρ $\left[\frac{kg}{m^3}\right]$	μ $\left[10^{-6}\frac{N\cdot s}{m^2}\right]$	κ $\left[10^{-3}\frac{W}{m\cdot K}\right]$	C_p $\left[\frac{J}{kg\cdot K}\right]$	ρ/μ $\left[10^{3}\frac{s}{m^2}\right]$	$g\beta/(\nu\alpha)$ $\left[10^{6}\frac{1}{m^3\cdot K}\right]$	α $\left[10^{-6}\frac{m^2}{s}\right]$
200	1.7690	13.36	18.10	1006.4	132.4	638.6	10.17
210	1.6842	13.92	18.95	1006.1	121.0	505.2	11.18
220	1.6071	14.47	19.80	1005.7	111.1	404.2	12.25
230	1.5368	15.01	20.63	1005.6	102.4	327.0	13.35
240	1.4728	15.54	21.45	1005.5	94.8	267.3	14.49
250	1.4133	16.06	22.26	1005.4	88.0	220.4	15.67
260	1.3587	16.57	23.05	1005.5	82.0	183.3	16.87
270	1.3082	17.07	23.84	1005.5	76.6	153.6	18.12
280	1.2614	17.57	24.61	1005.7	71.8	129.6	19.40
290	1.2177	18.05	25.38	1006.0	67.5	110.1	20.72
300	1.1769	18.53	26.14	1006.3	63.5	94.1	22.07
310	1.1389	19.00	26.87	1006.8	59.9	80.9	23.43
320	1.1032	19.46	27.59	1007.3	56.7	70.0	24.83
330	1.0697	19.92	28.30	1007.9	53.7	60.8	26.25
340	1.0382	20.37	29.00	1008.5	51.0	53.1	27.70
350	1.0086	20.81	29.70	1009.2	48.5	46.5	29.18
360	0.9805	21.25	30.39	1010.0	46.1	41.0	30.69
370	0.9539	21.68	31.07	1010.9	44.0	36.2	32.22
380	0.9288	22.11	31.73	1012.0	42.0	32.1	33.76
390	0.9050	22.52	32.39	1013.0	40.2	28.6	35.33
400	0.8822	22.94	33.05	1014.2	38.5	25.5	36.94

B2. A single-effect evaporator is used to concentrate7 kg/s of a solution from 10% to 50% of solids. Steam is available at a pressure of 205 kN/m^2 (saturation temperature = 394 K and enthalpy = 2530 kJ/kg) and the evaporation takes place at pressure of 13.5 kN/m^2. If the overall heat transfer coefficient is 3 kW/m^2 K, and the feed to the evaporator is at 294 K and the condensate leaves the heating space at 352.7 K, calculate

(a) **[10 points]** The amount of steam used.

(b) **[15 points]** The heating surface area required.

DATA:
Temperature of dry and saturated steam at 13.5 kN/m^2 = 394 K
Enthalpy of dry and saturated steam at 13.5 kN/m^2 = 2530 kJ/kg
Boiling point of water at 13.5 kN/m^2 = 325 K
Total enthalpy of steam at 325 K = 2594 kJ/kg
Specific heat capacity of 10% solution = 3.76 kJ/kg K
Specific heat capacity of 10% solution = 3.14 kJ/kg K

B3. A shell-and-tube heat exchanger is used to heat water (in the tube side) from 30 °C to 45 °C at a mass flow rate of 14,400 kg/hr. The shell side fluid used for heating is water entering at a temperature of 90 °C with a mass flow rate of 120 kg/min. A single shell pass is utilized for this operation. The overall heat transfer coefficient based on inside tube area is 1390 W/m^2 °C. Each tube has an inside diameter of 1.875 cm, and require an average water velocity of 37.7 cm/s. The available unit floor space limits the tube length to a maximum of 1.75 m.

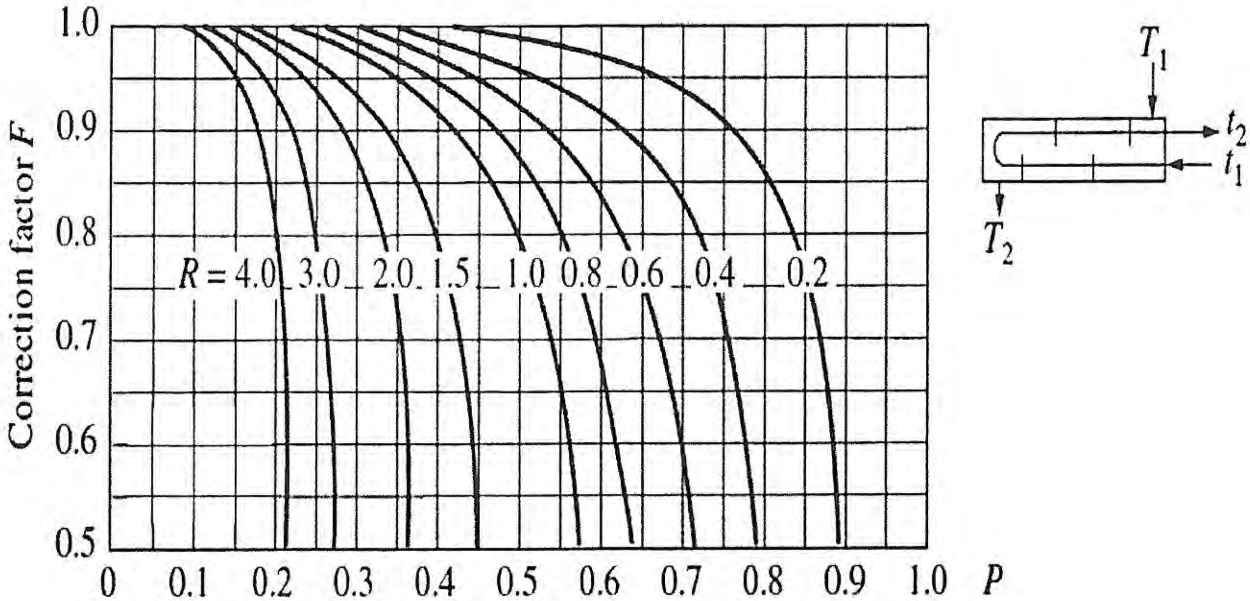
Using the heat exchanger correction factor plot below, calculate

(a) **[12 points]** Number of tubes required

(b) **[3 points]** Number of tubes per pass

(c) **[10 points]** Length of each tube

DATA:
Density of water = 993 kg/m^3
Specific heat capacity of water = 4174 J/kg K


Correction factor F
1.0
0.9
0.8
0.7
0.6
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
P
R = 4.0
3.0
2.0
1.5
1.0
0.8
0.6
0.4
0.2
T1
T2
t1
t2